

ESA SPACE WEATHER NETWORK SERVICE
REPORT of ANEMOS/NKUA TEAM
Geomagnetic conditions Service Center -G.171 Product
“Automated Process of the ap Prediction tool”

The Severe geomagnetic storm (G4) on March 24, 2024

1. Solar Activity

During the current solar cycle 25 on March 24, 2024, a severe geomagnetic storm (G4) observed at the Earth was occurred. This storm was noticed due to the effect of the CME that was observed on the Sun on March 23, 2024 at 01:25 UT ([CME Scoreboard \(nasa.gov\)](https://cme.scoreboard.nasa.gov/)) with radial velocity equal to 1613 Km/s. This CME was expected to reach Earth between March 24 at 07:46 UT and March 25 at 06:42 UT according to Effective Acceleration Predicted Model-EAM of the National and Kapodistrian University of Athens (Paouris and Mavromichalaki, 2017; 2017). The CME was associated with a X1.1 class solar flare from AR3614 peaking on March 23, 2024 at 01:33 UT (www.SolarMonitor.org). The actual shock arrival time of the above CME was noticed on March 24, 2024, at 14:10 UT producing a severe geomagnetic storm of level G4.

Moreover, a coronal hole at southern hemisphere rotated across the central meridian on March 20-22, 2024 (Figure 1). The results of solar wind flowing from this coronal hole were expected to reach Earth on March 24-25, 2024.

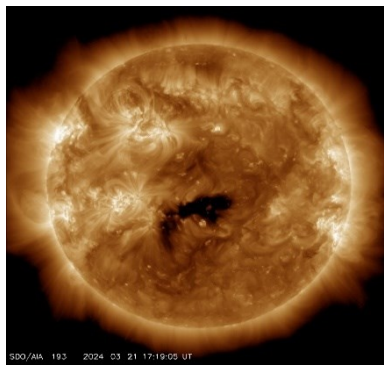


Figure 1: The coronal hole on March 2, 2024 as seen from SDO/AIA. (<http://sdo.gsfc.nasa.gov/data/aiahmi/>)

2. Solar Energetic Particle Events

GOES Proton Flux for particles with energies above 10 MeV exceeded the SWPC 10 MeV warning threshold on March 23, 2024, at 08:10 UT due to the X1.1 solar flare. A solar radiation storm of level S2 was also observed (Figure 2).

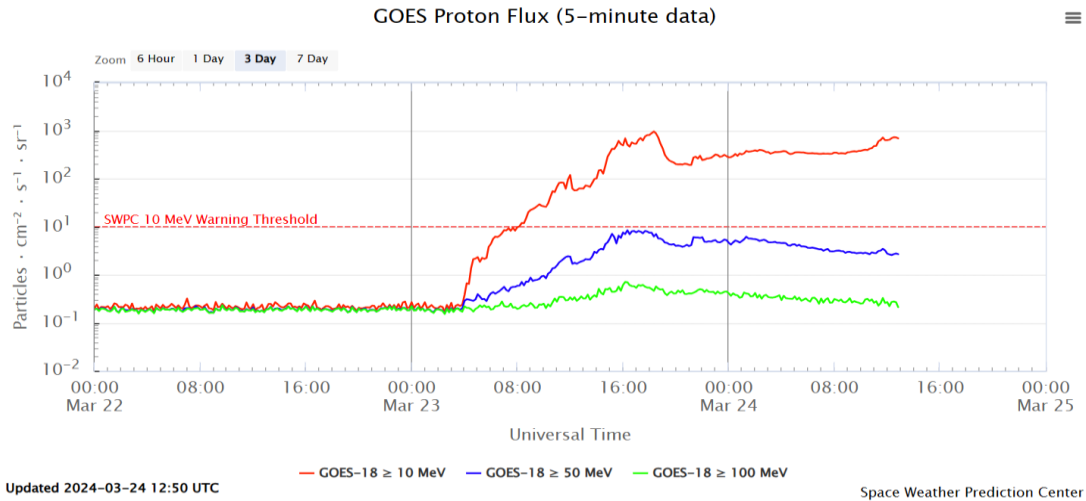


Figure 2: Alert signal issued by Space Weather Prediction Center (SWPC) of NOAA.

3. Interplanetary conditions

Due to the effects of the CME observed on March 23, 2024, the solar wind speed reached a peak of about 863 Km/s on March 24, 2024 at 20:35 UT as detected from ACE. The arrival signature was characterized by a sharp decrease of the vertical component of IMF Bz reaching the value of -23nT on March 24, 2024 at 15:20 UT (Figure 3). (<http://www.swpc.noaa.gov/products/real-time-solar-wind>).

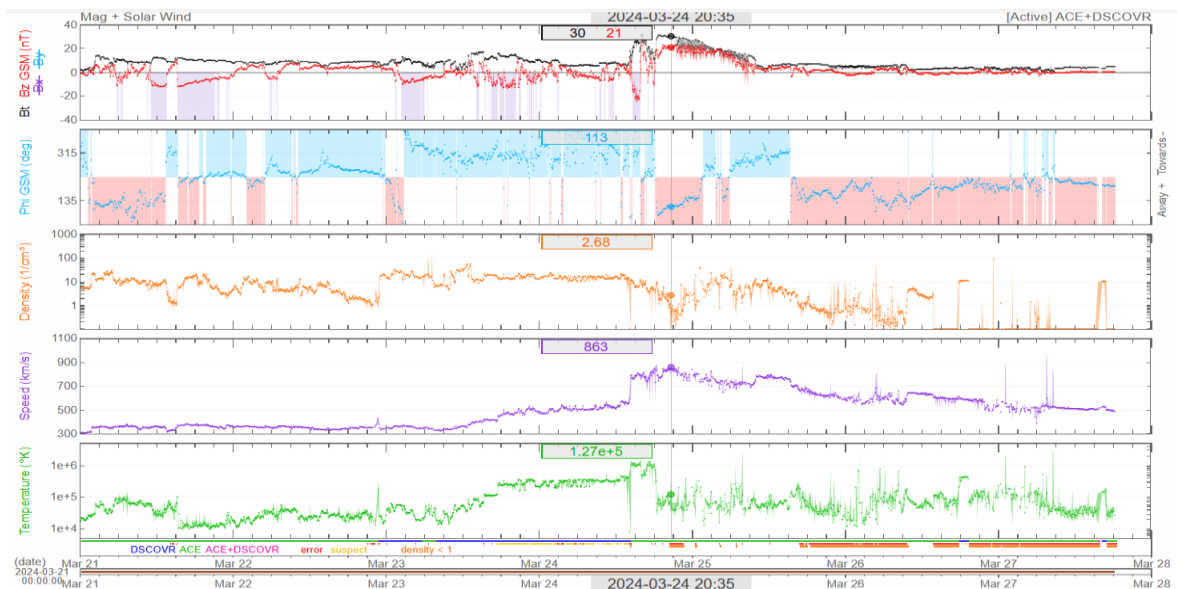


Figure 3: Solar wind speed and vertical component of IMF Bz from DSCOVR spacecraft.

4. Geophysical Activity

The time arrival of the above CME was successfully forecasted and reported from Athens Space Weather Forecasting Center ([ASWFC \(uoa.gr\)](http://aswfc.uoa.gr)) (figure 4).

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Product: Daily Forecast of Geomagnetic Activity
Issued: 2024 March 24 08:25UTC
Prepared by the Athens Space Weather Forecasting Center
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I. Solar activity
--Current Status
Solar Flux (10.7cm) measured on 23.03.2024 at 23:00 UTC was 209 sfu.
The background X-Ray flux is at the class C3.2 level.
One X1.1 and twelve M class solar flares were produced on March 23.
AR3614 erupted on March 23 at 01:33 UT peak time producing a X1.1 class solar
flare and a radioblackout of category R3.
No obviously Earth directed CMEs were observed in available LASCO imagery on
March 20-22.
A coronal hole (CH1207) at southern hemisphere rotated across the central
meridian on March 20-22.
---CME arrival forecast
A partial halo CME was observed after the X1.1 flare on March 23 at 01:25 UT.
This CME could reach Earth between on March 24 at 07:46 UT and on March 25 at
06:42 UT accordingg to EAM predictions.

II. Solar Energetic Particle Events
GOES Proton Flux for particles with energies above 10 MeV exceed the SWPC 10 MeV
warning threshold on March 23 at 08:10 UT due to the X1.1 solar flare. A solar
radiation storm of level S2 was also observed.

III. Interplanetary and Geomagnetic conditions
The solar wind speed measured by ACE satellite reached the max value 534 Km/s on
March 24 at 05:40 UT during the last 24 hours.
The solar wind speed from STEREO A was detected 450 Km/s during the last 24
hours.
The vertical component of IMF Bz reached the max value -13 nT on March 23 at
19:00 UT during the last 24 hours.
The geomagnetic field was at quiet to moderate storm (G2) levels during the last
24 hours.
The Kp index now is at unsettled levels with Kp=3.
The Dst index reached the value -82 nT on March 23 at 23:00 UT during the last 24
hours.

IV. 3-day Geomagnetic Activity Forecast
The geomagnetic field is expected to be at unsettled to moderate storm (G2)
levels on March 24, at unsettled to strong (G3) levels on March 25 due to the
affekt of a recurrent coronal hole high speed stream and the CME observed on
March 23 and at quiet to minor storm (G1) levels on March 26.

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Date  Ap index forecast  Geomagnetic Activity level
24.03.2024  25  Unsettled to Moderate (G2)
25.03.2024  45  Unsettled to Strong (G3)
26.03.2024  20  Quiet to Minor storm (G1)
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Athens Space Weather Forecasting Center
Physics Department, National & Kapodistrian University of Athens
Athens Neutron Monitor Station A.NE.MO.S
Tel.: +30 210 727 6901
email: spaceweather@phys.uoa.gr
URL: http://spaceweather.phys.uoa.gr
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Figure 4: Daily Space Weather Forecasting Report from A.NE.MO.S

Due to the arrival of the CME on March 24, 2024, the daily value of Ap index equal to 69 and the geomagnetic storm reached the level G4 (severe storm) with the corresponding Kp index equal to 8 (Figure 5). During the study period of the storm the Dst index reached the minimum value – 130 nT on March 24, 2024 at 21:00 UT (**Figure 6**) ([Real-time \(Quicklook\) Dst Index Monthly Plot and Table \(kyoto-u.ac.jp\)](http://real-time.quicklook.kyoto-u.ac.jp)).

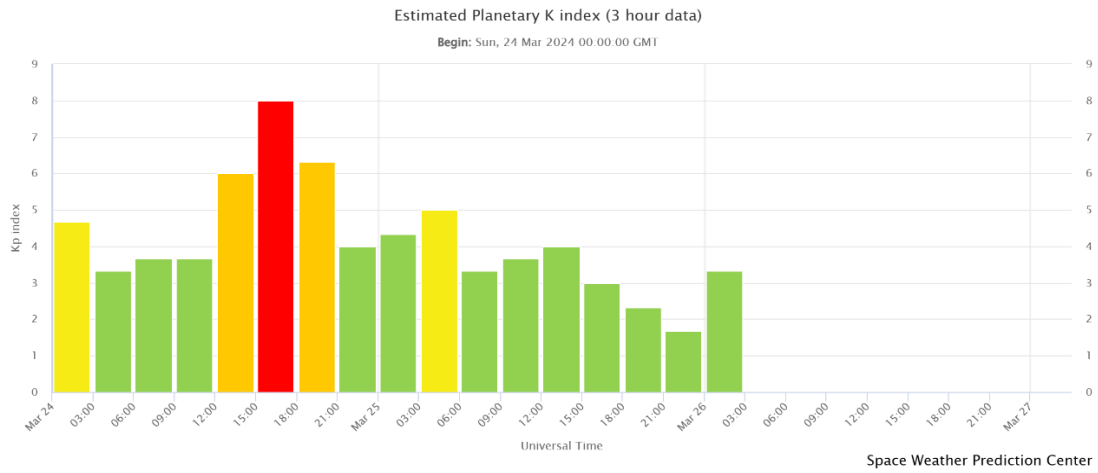


Figure 5: Kp index values for the period March 24-25, 2024.

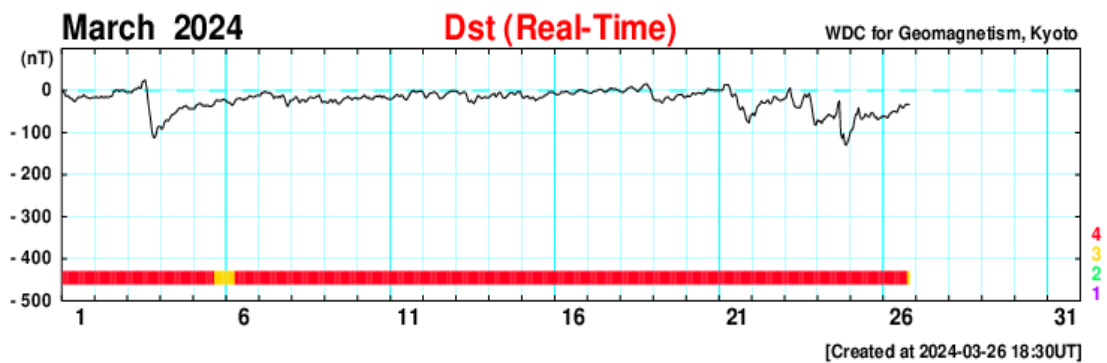


Figure 6: The variation of Dst index during the study period.

([Real-time \(Quicklook\) Dst Index Monthly Plot and Table \(kyoto-u.ac.jp\)](https://www.kyoto-u.ac.jp/~wdc/geomag/quicklook/dst/))

5. Cosmic rays

The results of the geomagnetic storm were spotted on the cosmic ray intensity. An important **Forbush decrease started on March 24, 2024** as a result of the arrival of the CME. It is remarkable the extremely rapid recovery of the Forbush decrease. The cosmic ray intensity recorded at the Athens neutron monitor station (cut-off rigidity 8.53 GV) is illustrated in Figure 7.

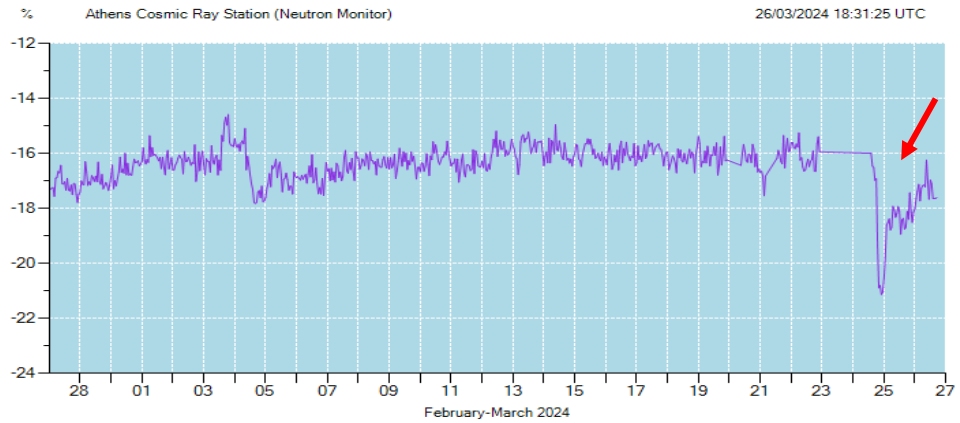


Figure 7: The counting rate of the Athens Neutron Monitor Station during March 2024.

6. The ap Prediction tool

The ap Prediction tool working on the G.171 Product estimated the arrival of the CME to the Earth on March 24, 2024 as well as the ap index fluctuations (Figure 8).

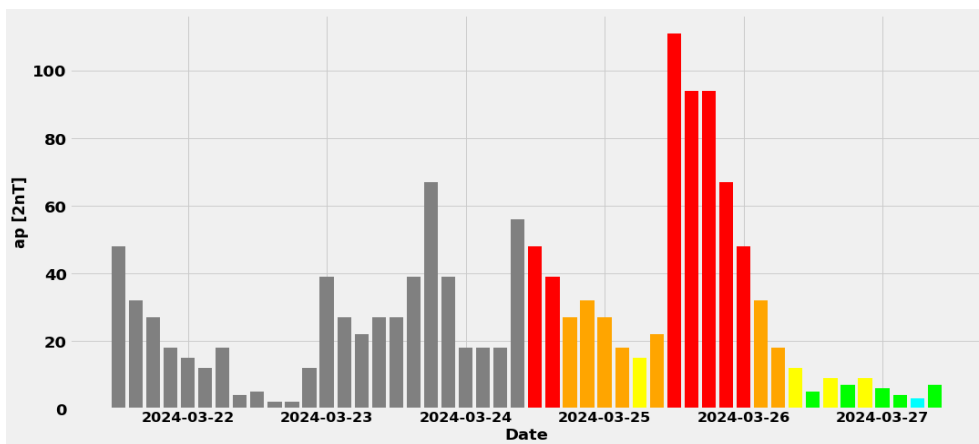


Figure 8: Colored scaled plot of ap values showing in grey color past 72 hours from March 21, 2024 to March 24, 2024 (actual data provided by GFZ) and the forecasted values for the next 72 hours from March 24, 2024 to March 27, 2024.

The algorithm of the tool calculated the arrival time of the CME using the Effective Acceleration Model – EAM. Also, linear regression machine learning algorithms are used for the estimation of the maximum ap value using as dependable variable the angular width and the median velocity (Stassinakis et al., 2023).

After this procedure the predicted ap_{max} was calculated to get a maximum value of 111 nT on March 25, 2024 at 12:00 UT which correspond to Kp value equal to 7. According to GFZ the actual value of ap_{max} equal to 236 on March 24, 2024 at 18:00 UT corresponding to Kp value equal to 8^+ (<http://www-app3.gfz->

potsdam.de/kp_index/qlyymm.html). The actual values of ap index from the tool during the arrival of CME are illustrated in Figure 9.

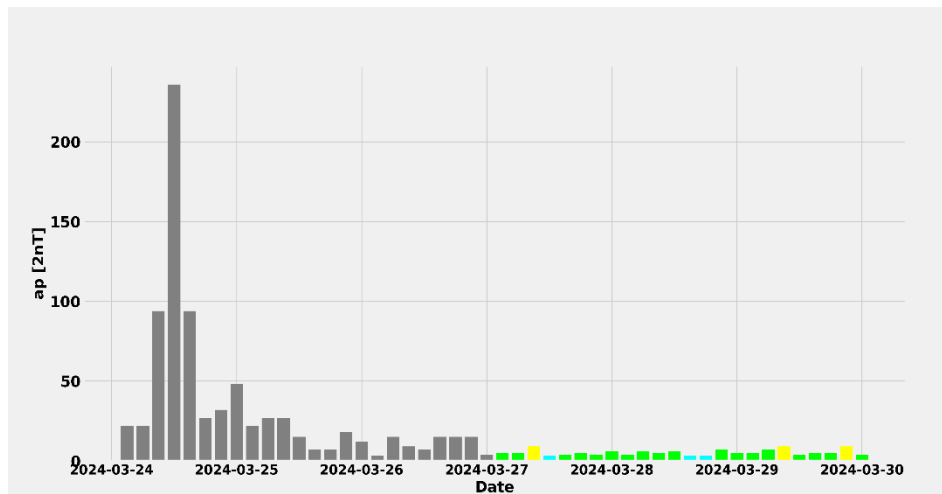


Figure 8: Colored scaled plot of ap values showing in grey color past 72 hours from March 24, 2024 to March 26, 2024 (actual data provided by GFZ) and the forecasted values for the next 72 hours from March 27, 2024 to March 30, 2024.

Concluding we think that the predicted values by the ap Prediction tool are more or less satisfactory and we hope that this will provide more improved results as the machine learning algorithms of the G.171 product are currently educated using data of a number of CMEs from previous years.

References:

- E. Paouris and H. Mavromichalaki: ‘Effective Acceleration Model for the arrival time of interplanetary shocks driven by coronal mass ejections’, *Solar Physics*, 292, 180, 2017 a, doi: 10.1007/s11207-017-1212-2.
- E. Paouris and H. Mavromichalaki: ‘Interplanetary coronal mass ejections resulting from Earth-Directed CMEs Using SOHO and ACE Combined Data During Solar Cycle 23’ *Solar Physics*, 292, 30, 2017 b, doi: 10.1007/s11207-017-1050-2.
- A.Stassinakis, M.Livada, M.Gerontidou, A.Tezari, H.Mavromichalaki, E.Paouris, P.Makrantonis: ‘Forecast of the Geomagnetic Index ap during CME events’, *European Space Weather Week*, 2023.